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(54) Electroforming mesh structures for use as camera tube electrodes

(57) A very fine metal mesh having a high aperture-to-wire area ratio, and thus a high transmissivity is electroformed using a master patterned substrate the groove pattern of which has an average groove depth sufficient to allow the electroformation of a mesh which, for a given weight of mesh metal, is contained wholely within the grooves and does not extend laterally beyond them across the master's face. The meshes currently in use and satisfactory for the larger tubes are not satisfactory for the smaller tubes since the methods used to produce metal mesh as fine as this, which are all variants of a basic electroforming technique in which the mesh metal is electronically deposited upon a corresponding mesh of a suitable metal that has itself been prepared by deposition in the grooves of a master mesh pattern "cut" into the surface of an inert, non-conductive substrate, suffer from a disadvantage that in the essential electrolytic deposition stage not only is the metal deposited (as is required) in and directly "above" the master pattern grooves but in addition it is deposited to either side of the grooves, so extending the eventual mesh wire laterally, and resulting in a significant reduction in the mesh's area ratio.

The invention provides an electroformed micron-fine mesh having an average wire width of not more than 5 micron (preferably about 2 micron) and an average wire depth-to-width ratio of 2:1 or greater (preferably about 2.5:1), and having a transmissivity at least 10% greater than a prior art mesh of comparable mesh metal weight and line frequency.

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SPECIFICATION

Mesh structures

This invention relates to mesh structures, and concerns in particular very fine metal mesh made by electroforming processes.

For various applications — thus, as an electrode in certain types of television camera tube — it is required to make and use a very fine metal mesh (referred to hereinafter as "a micron-fine mesh") having as many as 750, 1000, or even 1500 mesh lines per inch (the line frequency). A typical such prior art 1000 lines per inch mesh might weigh 1 milligram per sq. cm., and have a square pattern of mesh wires (or bars) 8 to 10 micron wide and 4 to 5 micron deep, and square mesh apertures 18 micron wide; it would thus have an aperture-to-wire width ratio — its bar aspect ratio — of about 2:1, an aperture-to-wire area ratio (a measure of the mesh's transmissivity, which in this case is somewhat less than 50%) of about 1:1, and a wire depth-to-width ratio of about 0.5:1.

Unfortunately, the meshes currently in use and satisfactory for the larger tubes are not satisfactory for the smaller tubes. Thus, while the 750 line meshes used in 30mm tubes may be scaled up to 1000 lines for satisfactory use in 1 inch tubes, when scaled up further to 1500 lines for use in the latest 2/3 inch tubes they become unacceptable, for the reasons now explained.

For mesh used as a camera tube electrode the most important features are the line frequency and the aperture-to-wire area ratio (1000 and about 1:1 in the above example), which critically affect mesh transmission. A number of different methods are used to produce metal mesh as fine as this, but in general all these methods are variants of a basic electroforming technique in which the mesh metal (usually copper or nickel) is electrolytically deposited upon a corresponding mesh of a suitable metal (usually silver or palladium) that has itself been prepared by deposition in the grooves of a master mesh pattern "cut" into the surface of an inert, non-conductive substrate (usually glass). In one such method the electroforming process is as follows:—

a) Palladium is sputter deposited onto the whole surface of an appropriately grooved glass master patterned substrate.
b) The deposited metal film is then rubbed off the master substrate surface, leaving sufficient metal in the grooves to form an electrically conductive mesh-like network.
c) After washing, the palladium network on the master substrate is electroplated with copper from a copper anode/copper sulphate electroplating solution.
d) After a further wash, the formed mesh is peeled off the master ready for use.

In order to ensure that the formed mesh is sufficiently strong it is necessary to arrange that the individual mesh wires have the requisite minimum dimensions. Unfortunately, in this regard all of those particular electroforming methods presently in use suffer from a severe disadvantage; in the essential electrolytic deposition stage not only is the metal deposited (as is required) in and directly "above" the master pattern grooves — that is perpendicular to the grooves — but in addition it is deposited to either side of the grooves (in the plane of the master substrate surface), so extending the eventual mesh wire laterally. The result is a mesh with wires which may have a width as great as twice that of their depth, and a significant reduction in the mesh's bar aspect and area ratios (which is most certainly not required for it may seriously affect the mesh's electron transmissivity). While this reduction in transmissivity may not be over large when the mesh is relatively coarse, it is much more serious when, as is the modern trend, the mesh is relatively fine. For example, with a conventional 750 lines per inch mesh having (roughly) a nominal wire width of 5 micron and a nominal aperture width of 30 micron an increase in wire width of, say, 2 micron might result in a relatively small change in area ratio, causing a transmissivity reduction of perhaps only 5% (from, say, 60% to 55%). However, with the newer 1500 lines per inch meshes having (roughly) a nominal width of 5 micron but a nominal aperture width as small as 10 micron, the same 2 micron wire width increase could result in a relatively large area ratio change, causing a corresponding transmissivity reduction of as much as 10% (from, say, 45% — which is already low — down to 35%), which is quite unacceptable.

The present invention seeks to overcome this problem of the lateral spreading of the mesh wires by the simple but apparently unconsidered expedient of using a master patterned substrate the groove pattern of which has an average groove depth sufficient to allow the electroformation of a mesh which, for a given weight of mesh metal, is contained wholely within the grooves and does not extend laterally beyond them across the master's face. As a result, for any given mesh, having a specified weight of mesh metal and a specified line frequency, the area ratio — the ratio of aperture area to wire area — and thus the transmissivity will be considerably improved for an inventive mesh as compared with a corresponding prior art mesh.

In one aspect, therefore, this invention provides an electroformed micron-fine mesh having an average wire width of not more than 5 micron and an average wire depth-to-width ratio of 2:1 or greater, and having a transmissivity of at least 10% greater than a prior art mesh of comparable mesh metal weight and line frequency.

The mesh of the invention has one major advantage over those meshes presently used; for a given weight of mesh metal a mesh of a particular line frequency has a higher — and thus better — area ratio (the depth dimension of the wires gives them their strength without reducing — as does a comparable increased width dimension — the favourable aperture size and thus mesh area ratio). This improved area ratio results in the obtained increase in transmissivity at any specified line frequency, and so provides an improved signal-to-noise ratio from a given value of resolvable optical detail (resolution), or a higher resolution value for a given signal-to-noise ratio.

The mesh of the invention can be other than a "square" mesh (where the mesh wires are in equally spaced rows and columns so as to defined square or nearly square apertures) — for example, the mesh apertures might be oblong, circular or of some irregular shape. Nevertheless, square meshes are in fact preferred (for reasons connected primarily with the ease of preparing the master mesh patterns), and in such a case references herein to the aperture-to-wire area ratio may be replaced by references to the aperture-to-wire width ratio (the mesh "aspect ratio") which, numerically, is usually very similar to — although slightly bigger than — the area ratio.

Similarly, the mesh of the invention can have wires which are of other than constant width/depth/cross-sectional area, but it is preferred to employ meshes where these wire dimensions are constant. The expressions "average wire width" and "average wire depth-to-width ratio" are intended to be construed on the basis of a more or less constant wire depth (the dimension normal to the mesh plane) and the average of a possibly varying wire width (the dimension in the mesh plane between adjacent apertures). In a conventional square mesh the terms "width" and "depth" have their normal significance, and are both effectively constant.

The meshes of the invention are stated to be "micron-fine", and by this term there is meant, in general, meshes which have a transmissivity of about 45% or better, a weight of not more than 1.5 milligrams per sq. cm., and have more than 500 mesh wires per inch, each wire being at most 5 micron wide and being spaced from the next wire by a mesh aperture at least 10 micron wide. With the observation that, again in general, as mesh line frequency increases so the preferred upper limit for wire width drops and the preferred lower limit for aperture width increases, more specific examples of 45% plus transmissivity meshes useful in camera tubes and to be considered as falling within the term "micron-fine" are shown in the following Table.

TABLE

Related size of camera tube.	Mesh Weight (mg/cm²)	Line frequency (lines/inch)	Preferred Aperture lower limit (μ)	Preferred wire width upper limit (μ)	Transmissivity (%)
30 mm	1.5	750	30	5	70
1 inch	1.0	1000	20	4	64
2/3 inch	1.0	1500	10	2	64

A particular micron-fine 1500 lines per inch square mesh of the invention, useful as a mesh electrode in a 2/3 inch television camera tube, and weighing 1.0mg/cm², has a wire width of 2 micron and an aperture width of nearly 15 micron, giving an area ratio of about 3.5:1, an aspect ratio of about 7:1, and a transmissivity of about 80%.

The mesh of the invention has a wire depth-to-width ratio of at least 2:1 in order that the individual wires should contain enough metal to give them — and the mesh — the requisite minimum strength. Now, since it is the wire that gives the mesh what strength is has, and since it is undesirable to increase the mesh strength by increasing the wire width (so increasing the aspect ratio), it follows that increases in mesh strength must come from increases in mesh wire depth — and that, if the mesh weight is to be kept constant (as is preferred) this depth increase must be at the expense of the wire width. There is, of course, no abstract requirement for any particular absolute strength value, though in practice it is necessary to handle the mesh during production, and a camera tube mesh is usually tensioned *in situ* so as to reduce the likelihood of it physically vibrating under the stimulus of low frequency sound (which vibrations could cause undesirable fluctuations in the tube's signal output); these factors necessitate a certain minimum mesh strength. Furthermore, in practice it is at present extremely difficult consistently and reliably to obtain master pattern groove widths of less than 1 micron (even though in theory a mesh wire of negligible width would be best from the point of view of, say, resolution), and 2 micron wide grooves are usually the best available. For very high line frequencies (say, 1500 lines per inch) almost the absolute minimium mesh strength at a reasonably attainable minimum width (2 micron) needs a minimum wire depth of about 4 micron, and 5 micron is preferred (a depth-to-width ratio of 2.5:1), while as the line frequency decreases (say, to 1000 lines per inch) the necessary minimum wire depth increases (perhaps as much as 10 micron — a depth-to-width ratio of 5:1), although with low line frequencies wider wire (say, 4 micron) can be tolerated, allowing the wire to be less deep (say, 8 micron, giving a depth-to-width ratio of 2:1). The preferred 1500 line mesh mentioned above uses mesh wires about 2 micron wide and about 5 micron deep.

There is, on the other hand, a strong preference for a general minimum value for the mesh wire width in order to avoid the depth of wire necessary (to give the wire sufficient strength) becoming so great as to cause the mesh to appear (to electrons passing therethrough) as a lot of tubes packed side-by-side like the microchannel plates used in certain types of image intensifier. For this reason, the wire depth should most preferably be less than about 30 micron — giving, with a 2 micron wide wire, a preferred maximum wire depth-to-width ratio of 15:1.

A preferred wire depth-to-width ratio is in the range of from 2:1 to 10:1.

In another aspect of this invention provides a process for the preparation of a micron-fine mesh of the invention, in which, using techniques known *per se,* the mesh is produced by electrolytically depositing sufficient of the chosen mesh metal wholely into the grooves of a master mesh pattern in the surface of a suitable substrate, the grooves having an average width of not more than 5 micron and and average depth-to-width ratio of 2:1 or greater.

As might be expected, the remarks concerning the dimensions of the mesh itself apply, *mutatis mutandis,* to the substrate groove pattern.

A number of techniques are presently available for cutting groove patterns of the general type required by the invention. Two appear particularly suitable, depending on the substrate material; one of these is that technique known as reactive sputter etching, and the other is the technique known as anisotropic etching. These techniques are described in some detail in (respectively) Appl. Phys. Lett. 32(3) 1/2/78 pp 163—165 (by Lehmann and Widmer) and RCA Review, June 1970, pp271—275 (by Stoller). Briefly, however, in the first a silicon or silicon dioxide substrate is conventionally rf-sputter etched (after first being suitably masked with a photoresist) but in a low pressure CHF_3 atmosphere rather than in argon or CF_4, while in the second the (110) face of a suitably cut silicon single crystal is chemically etched with hot concentrated caustic potash (after first being suitably masked with a silicon dioxide resist layer), the etch action being quite anisotropic and leaving groove walls normal to the (110) face.

It should be observed that because of the constraints imposed by the geometry of the silicon crystal used in the second method (anisotropic etching), this particular method can only be employed to produce a master groove pattern, and a mesh prepared therefrom, where the apertures are a series of regularly arranged parallelograms with angles of 109°47′ and 70°53′.

As stated above, the techniques utilized for master pattern preparation are in general well known. In addition to the features already briefly outlined, it can here be said, for guidance, that:—

Suitable photoresist materials are UV-active materials such as Kodak MICRONEG (a negative resist developed with white spirit and subsequently removed with H_2SO_4/H_2O_2) or Shipley AZ 111 (a positive resist developed with NaOH and subsequently removed with acetone).

Sputter etch times naturally depend upon the power involved and the depth required, but using conventional procedures a 5 micron etch can be attained in quartz in about 2 hours. Anisotropic etch times also vary depending upon the concentration and temperature of the KOH used, but a 5 micron etch can be achieved in about 30 seconds using boiling 1000 gpl KOH.

The invention extends, of course to a micro-fine electroformed mesh whenever prepared by a process as described and claimed herein.

The following Examples are given, though only by way of illustration, to show details of various aspects of the invention.

EXAMPLE 1

Preparation of a micro-fine copper mesh suitable for use in a vidicon-type television camera tube.

Stage A: Preparation of the master patterned substrate.

(i) Image-forming using a photo resist

A 13 cm square plate of quartz flat to within 4 light bands was cleaned, and coated with a 1μm layer of Kodak MICRONEG ultra-violet sensitive resin negative photoresist. After 45 secs. exposure to UV radiation from a high pressure mercury vapour lamp through a square mesh mask (carrying a regular square array of opaque lines 2μ wide and 14μ apart), the plate was developed with spirit to give an image of the mask on the plate surface.

(ii) Etching to produce the grooves

The quartz substrate was then subjected to an RF sputter etch process of the type described by Lehmann and Widmer (Appl. Phys. Letters 32(3), 1/2/78, pp 163—165), using CHF_3 as the reactive gas. After two hours the substrate was removed from the sputter system, and the remaining photoresist chemically removed with H_sSO_4/H_2O_2. The master so prepared had grooves 5μ deep, and was ready for use in the mesh manufacturing process.

Stage B: Preparation of the mesh.

(i) Deposit of conductive base into the master grooves

The master pattern quartz plate was sputter deposited with palladium (using a high voltage DC discharge in 0.1 mm Hg Argon with a palladium cathode). The excess deposited palladium film was then rubbed off the surface of the substrate, leaving sufficient metal in the grooves to form an electrically conductive mesh-like network, and the whole was washed in water.

(ii) Electroplating the network with copper.

The washed palladium network was then electroplated with copper using a copper anode/acetic saturated copper sulphate electroplating solution. The plating was effected for about 10 minutes with a current of about 1 amp.

After a further water wash, the formed mesh was peeled off the master. It weighed about 1.0mg/cm^2, its mesh wires were 2μ wide and 5μ deep (a depth-to-width ratio of about 2.5:1), its apertures were about 14μ wide, and it had a transmissivity of well over 70%.

EXAMPLE 2

Preparation of a micron-fine copper mesh

Stage A: Preparation of the master patterned substrate

A 3 inch diameter wafer of single crystal silicon cut to present a (110) crystal face, having a vapour deposited 1 micron thick silicon oxide layer thereon, was given a Shipley AZ 111 UV-sensitive resin positive photoresist on the oxide surface. This was exposed to UV through a mask consisting essentially of parallelograms with angles of 109°47′ and 79°53′, with a line width of 2μ and line spacing of about 14μ. After developing the resist layer with NaOH, the photoresist pattern was then itself used as a mask to etch through the silicon dioxide layer using standard buffered HF solution to leave the latent groove pattern of exposed single crystal silicon in the matrix of resist-covered oxide parallelograms. The remaining photoresist was then removed with acetone, and the silicone slice subjected to boiling 1000 gpl potassium hydroxide solution for about 30 seconds, giving a groove depth of about 5μ.

The remaining silicon dioxide surface layer was removed from the master surface (again using HF solution) so as to avoid the small amount of undercut which might have occurred making the subsequently electroformed mesh difficult to remove from the master.

Stage B: Preparation of the mesh.

In a manner essentially identical to that of Example 1, State B, the silicon-wafer master substrate was used to make a copper mesh.

CLAIMS:

1. An electroformed micron-fine mesh having an average wire width of not more than 5 micron and an average wire depth-to-width ratio of 2:1 or greater, and having a transmissivity at leat 10% greater than a prior art mesh of comparable mesh metal weight and line frequency.

2. A mesh as claimed in claim 1, wherein the mesh wires are in equally spaced rows and columns so as to define square or nearly square apertures.

3. A mesh as claimed in either of the preceding claims, wherein the wires are of constant width, depth and cross-sectional area.

4. A mesh as claimed in any of the preceding claims, which mesh has a transmissivity of 45% or better, a weight of not more than 1.5 milligrams per sq. cm., and more than 500 mesh wires per inch, each wire being at most 5 micron wide and being spaced from the next wire by a mesh aperture at least 10 micron wide.

5. A mesh as claimed in any of the preceding claims, wherein the wire depth-to-width ratio is from 2:1 to 10:1.

6. A mesh as claimed in any of the preceding claims, which mesh is a 1500 lines per inch square mesh weighing 1.0mg/cm^2, and has a wire width of 2 micron, a wire depth of 5 micron, and an aperture width of nearly 15 micron.

7. An electroformed micron-fine mesh as claimed in any of the preceding claims and substantially as described hereinbefore.

8. A process for the preparation of an electroformed micron-fine mesh as claimed in any of the preceding claims, in which the mesh is produced by electrolytically depositing sufficient of the chosen mesh metal wholely into the grooves of a master mesh pattern in the surface of a suitable substrate, the grooves having an average width of not more than 5 micron and an average depth-to-width ratio of 2:1 or greater.

9. A process as claimed in claim 8, in which the electrolytic deposition is effected in a conventional manner, having first deposited within the grooves a layer of metal to form the electrolytic cell cathode element.

10. A process as claimed in claim 9, in which the mesh metal is copper, and is electrolytically deposited upon a preliminary layer of palladium sputter deposited within the grooves.

11. A process as claimed in any of claims 8 to 10, in which, in a preliminary stage, the master groove pattern has been cut in the substrate either by that technique known as reactive sputter etching, or by that technique known as anisotropic etching.

12. A process as claimed in claim 11, in which a silicon or silicon dioxide substrate is rf-sputter

etched (after first being suitably masked with a photoresist) in a low pressure CHF_3 atmosphere, or the (110) face of a suitably-cut silicon single crystal is chemically etched anisotropically with hot concentrated caustic potash (after first being suitably masked with a fine silicon dioxide resist layer).

13. A process as claimed in any of claims 8 to 12 and substantially as hereinbefore described.

14. An electroformed micron-fine mesh whenever prepared by a process as claimed in any of claims 8 to 13.

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